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Research Article

Mammal use of underpasses to cross Route 606 in Guacimal, Costa Rica

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Abstract

Roads severely affect the health of ecosystems across the globe by fragmenting and diminishing habitats, reducing population connectivity, and increasing animal mortality. Wildlife underpasses allow for increased road permeability–the ability for animals to safely cross the road. Despite growing success in other regions, little is known about underpass usage in Central America. In this study, I monitored two dry circular culverts and two unfenced tunnels with barbed wire partially blocking their entrances on Route 606 in Guacimal, Costa Rica, from 14 November to 6 December 2021 using 15 camera traps to assess which species used them to cross. Twelve species used the culverts and tunnels for a total of 108 individual crossings. The tunnels were used, in descending order, by agouti (*Dasyprocta punctata*), common opossum (*Didelphis marsupialis*), dog (*Canis familiaris*), nine-banded armadillo (*Dasyous novemcinctus*), cat (Felis catus), Norway rat (*Rattus norvegicus*), ocelot (*Leopardus pardalis*), squirrel (*Sciurus variegatoides*), northern tamandua (*Tamandua mexicana*), and coati (*Nasua narica*). The circular tunnel, Tunnel 1, was used more frequently and by a greater diversity of species than observed in the square tunnel, Tunnel 2. The two smaller culverts were used by common opossum (*Didelphis marsupialis*), cat (*Felis catus*), rat opossum (*Micoureus alstoni*), and Watson's climbing rat (*Tylomus watsoni*). Culvert 2 was used more frequently; however, Culvert 1 was used by a greater diversity of species. This study highlights wildlife underpasses as a critical strategy for biological conservation in Costa Rica through improved road safety and habitat connectivity.

Key words: Camera trapping, Central America, habitat fragmentation, road ecology, wildlife crossing structures

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Introduction

Habitat space is essential for each species to survive and maintain a reproducing population. Habitat fragmentation is the process by which an area of habitat is divided into two or more smaller fragments that are oftentimes surrounded by areas inhospitable to the species that reside there (Didham 2010; Wilson et. al 2016). This fragmentation can occur when human activity transforms natural areas into roadways, agricultural plots, human settlements, and more, that results in a disconnect between the remaining fragments and often a net loss of habitat (Mullu 2016). The species remaining during and after fragmentation and habitat loss are often at greater risk of inbreeding, reduced

diversity, genetic drift, and subsequent extinction due to their isolation (Dixo et al. 2009; Didham 2010; Haddad et al. 2015; Wilson et al. 2016). In addition, when individuals attempt to access isolated fragments divided by dangerous roadways, they inevitably increase wildlife-vehicle collisions, which further decreases genetic diversity and endangers motorists (Barbosa et al. 2020).

Wildlife crossing structures present one possible mitigation to habitat fragmentation by increasing road permeability–the ability for animals to safely cross the road. An effective crossing structure allows safe and continuous passage through an inhospitable environment that separates two habitats (Bennet 1999). Wildlife underpasses are structures that allow animals to pass under a road and will generally include both underpass tunnels and culverts in this study, although they both have distinct attributes. An assumption is made when animal crossing structures are implemented that animals will prefer to use them to move between fragmented habitats rather than cross through the inhospitable environment. Despite being in one of the most biologically diverse regions in the world, the use of these underpasses as effective tools for conservation is critically under-studied in Central America (Venegas 2018; Villalobos-Hoffman et al. 2022).

Two unfenced subterranean animal crossing tunnels, one circular and one square, were built in 2016 to mitigate the fragmentation caused by the Route 606 roadway from Guacimal to Monteverde, Costa Rica, based on locals' observations of roadkill and animal crossings (Camacho and Chinchilla 2013). Notably, after they were installed, the landowners directly surrounding the tunnels partially blocked their entrances with barbed wire fences to prevent livestock from using them. This roadway is particularly treacherous for wildlife moving between fragmented habitats because tourism and travel in the area creates a higher-than-average traffic density (Naranjo-Ureña et al. 2019). Subterranean tunnels built for animal passage and culverts built for water diversion under roads have been shown to facilitate travel between fragments for various small, medium, and large mammals in South, North, and Central America (Beier et al. 2008; Venegas 2018; Abra et al. 2020; Villalobos-Hoffman et al. 2022). The two tunnels and two culverts along Route 606, however, had not been previously monitored to find out what animals use them to cross. In this brief study, I investigated differential usage of these wildlife underpasses by local mammal species. I analyzed the effectiveness of these types of underpasses as a tool to mitigate fragmentation and conserve the health of local ecosystems through their ability to facilitate animal movement in these locations. Knowing which species use these corridors to cross the road can help determine which species' populations are positively affected by the underpasses and inform future conservation efforts.

Materials and methods

This study was conducted at the section of Route 606 through la Guaria on the road leading from Monteverde to Guacimal, a section of road that was first paved in 2017 and has frequent traffic (Naranjo-Ureña et al. 2019). The land fragments bisected by the road are a mixture of pasturelands with secondary and primary growth forests. Culvert 1 and 2 locations: (10.250, -84.839) and (10.246, -84.844). Tunnel 1 and 2 locations: (10.229, -84.851) and, (10.226, -84.851) (Fig. 1).

Bushnell HD cameras traps and mud track stations were used to identify which mammal species are using the wildlife underpasses to cross under Route

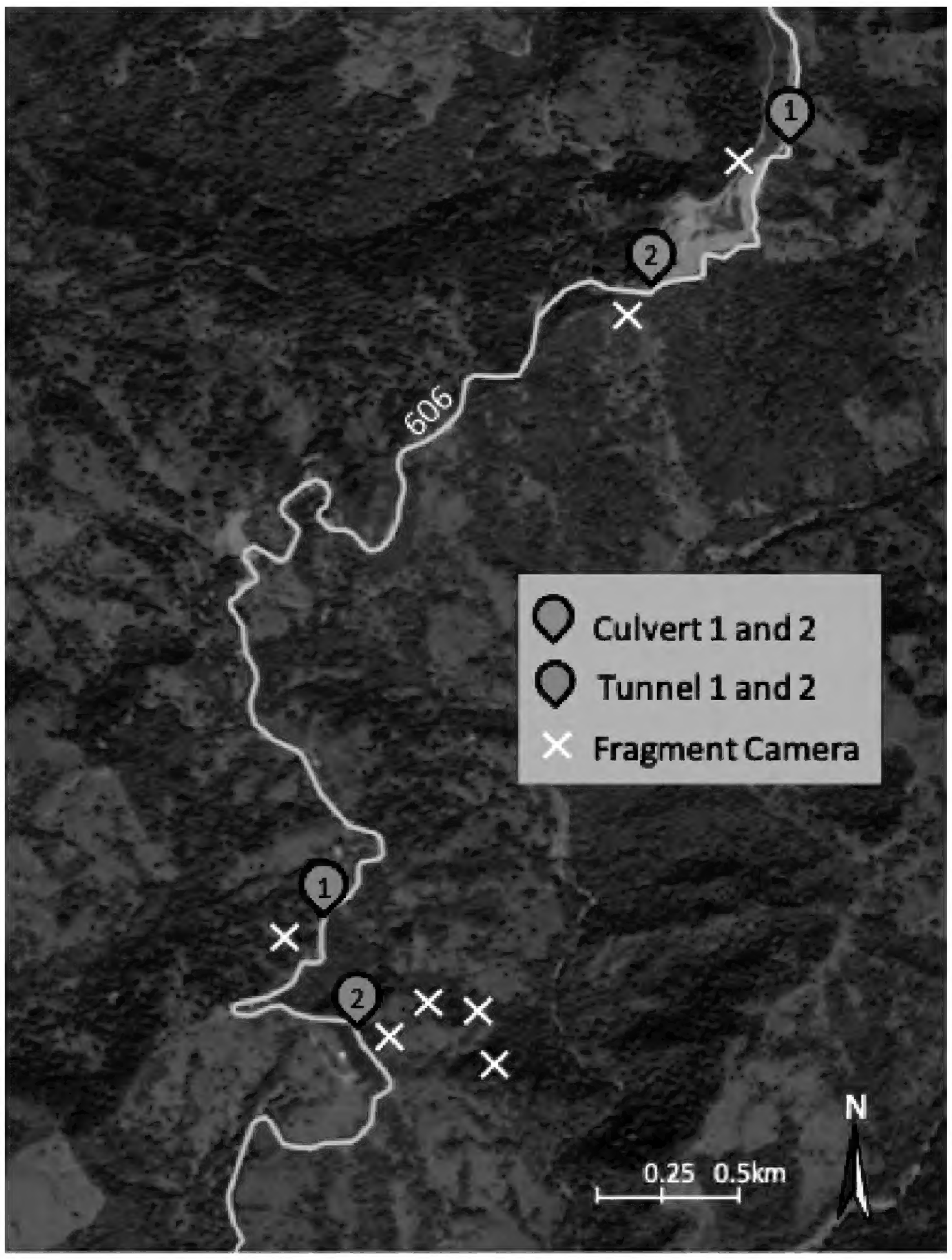

Figure 1. Underpass locations. Satellite view of the underpass locations between Guacimal and Monteverde along Route 606. Orange points indicate Culvert 1 and 2. Yellow points indicate circular Tunnel 1 and square Tunnel 2. White Xs indicate locations for camera traps placed in the land fragments surrounding the underpasses. Map Data: Google (C) 2023 CNES / Airbus, Landsat / Copernicus, Maxar Technologies, U.S. Geological Survey.

606. The camera traps were set on camera mode to 12 megapixels, 3 photo bursts, auto sensitivity, medium shutter speed, and 3-second exposure intervals. At each site, machetes were used to remove vegetation such as tall grass or vines from the two-meter area in front of the camera to reduce misfiring.

Three camera traps were positioned facing the entrances of the two larger subterranean tunnels–Tunnel 1 circular (radius 1 m) and Tunnel 2 square (height 1 m 77 cm, width 2 m 1 cm). One camera was placed at each tunnel on 14 November, to collect a week of preliminary data. In the tunnels, mud made with water and surrounding dirt was smoothed approximately 0.5 by 2 meters at each entrance to record animal tracks as supporting data for the cameras. Cameras were installed on 22 November 2021, at one end of two circular culverts (radius 86 and 88 cm), and removed on 6 December 2021. Seven cameras were placed from 22 November to 6 December throughout the land fragments directly surrounding the roadway at least 50 meters apart from each other to monitor immediate roadside and fragment species diversity. Memory cards and track stations were replaced every other weekday to ensure they were operational. Presence of roadkill, insects, or birds was noted during site visits. The photo data was reliably coded to assess species type and number of crossings by using photo references for identification. A "crossing" by a species was based on whether that animal was captured going into or out of the underpass. The presence of any species recorded in the track station was corroborated with camera trap footage.

Results

I observed twelve mammal species using the culverts and subterranean tunnels to cross under Route 606. Each species photographed using the tunnels or culverts to cross is listed in the tables below. The common opossum, agouti, and nine-banded armadillo were the native species that used the underpasses most frequently (Fig. 2).

Tunnel 1 was crossed more frequently and by a greater diversity of species than Tunnel 2. Tunnel 1 was crossed a total of 67 times by ten species, while Tunnel 2 was crossed a total of 24 times by four species (Fig. 3).

Culvert 2 was crossed more frequently than Culvert 1; however, Culvert 1 was used by a greater diversity of species. Culvert 1 was crossed a total of five times by three species, while culvert 2 was crossed a total of 12 times by two species (Fig. 4).

Some animals were documented in the surrounding land fragments but were not observed using one or more of the underpasses. Species such as the olive

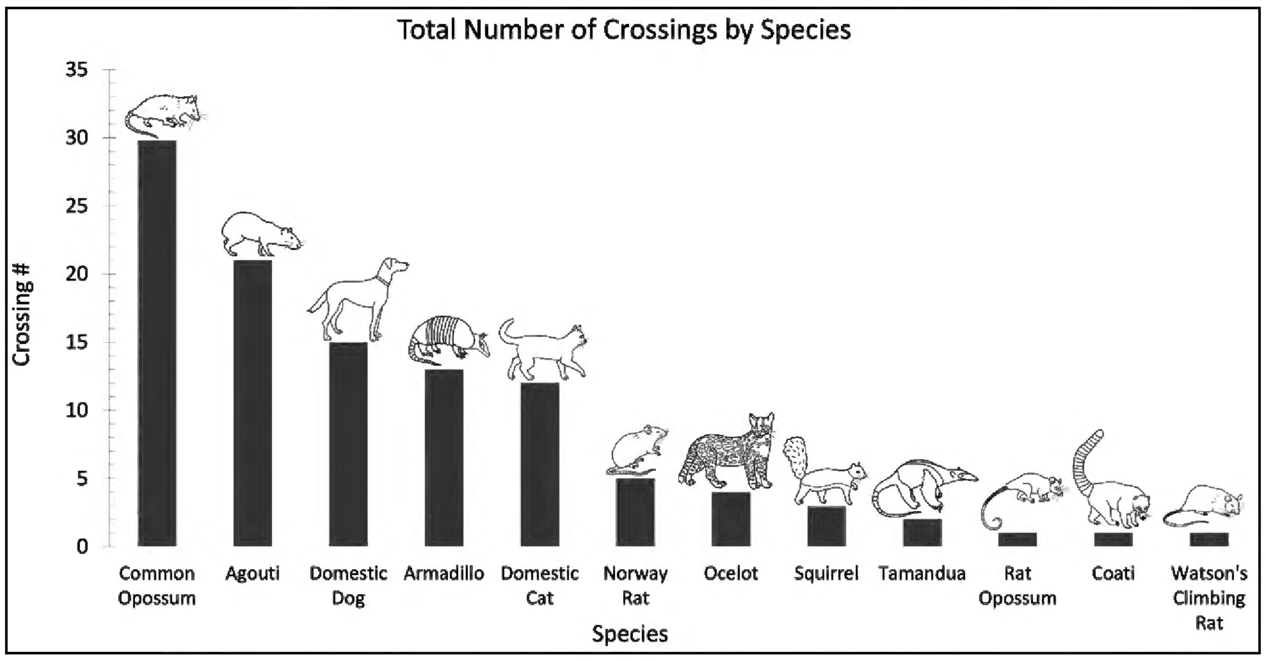

Figure 2. Sum of total detected crossings by species across all underpasses.

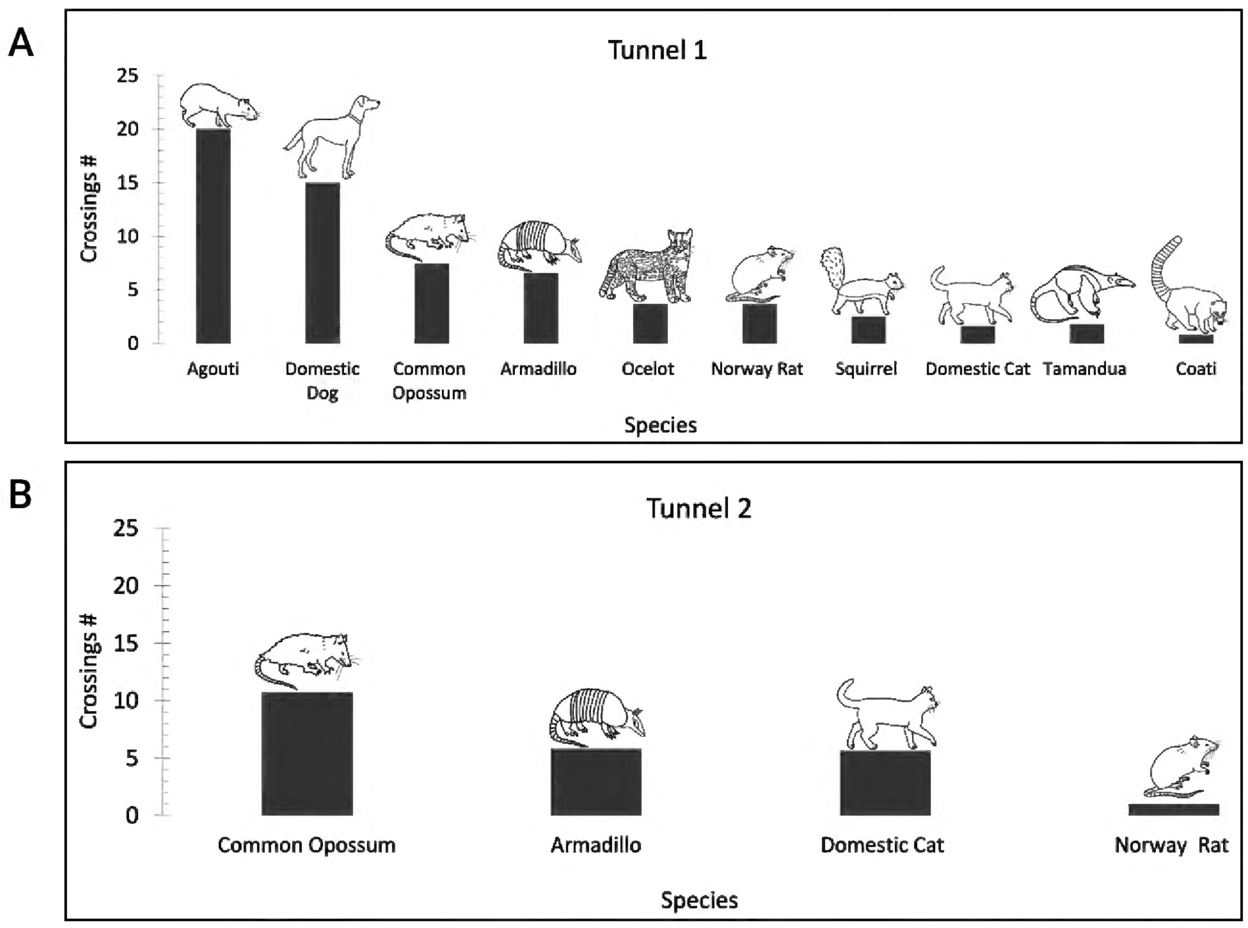

Figure 3. Number of detected crossings by species through Tunnel 1 and 2.

sparrow (*Arremonops rufivirgatus*), cow (*Bos taurus*), black iguana (*Ctenosaura similis*), Swainson's thrush (*Catharus ustulatus*), spiny pocket mouse (*Heteromyidae*), rice rat (*Oryzomys*), Watson's climbing rat (*Tylomus watsoni*), coyote (*Canis latrans*), chicken (*Gallus Domesticus*), and gray fox (*Urocyon cinereoargenteus*) were captured by camera traps in the land fragments but not observed using any of the underpasses to cross (Table 1). Some species such as agouti and northern tamandua were documented using only Tunnel 1 and not Tunnel 2 to cross (Table 1 and Fig. 3).

Activity of native species using the corridors was most common at night, while activity of domesticated species using the corridors was most common during the day (Fig. 5).

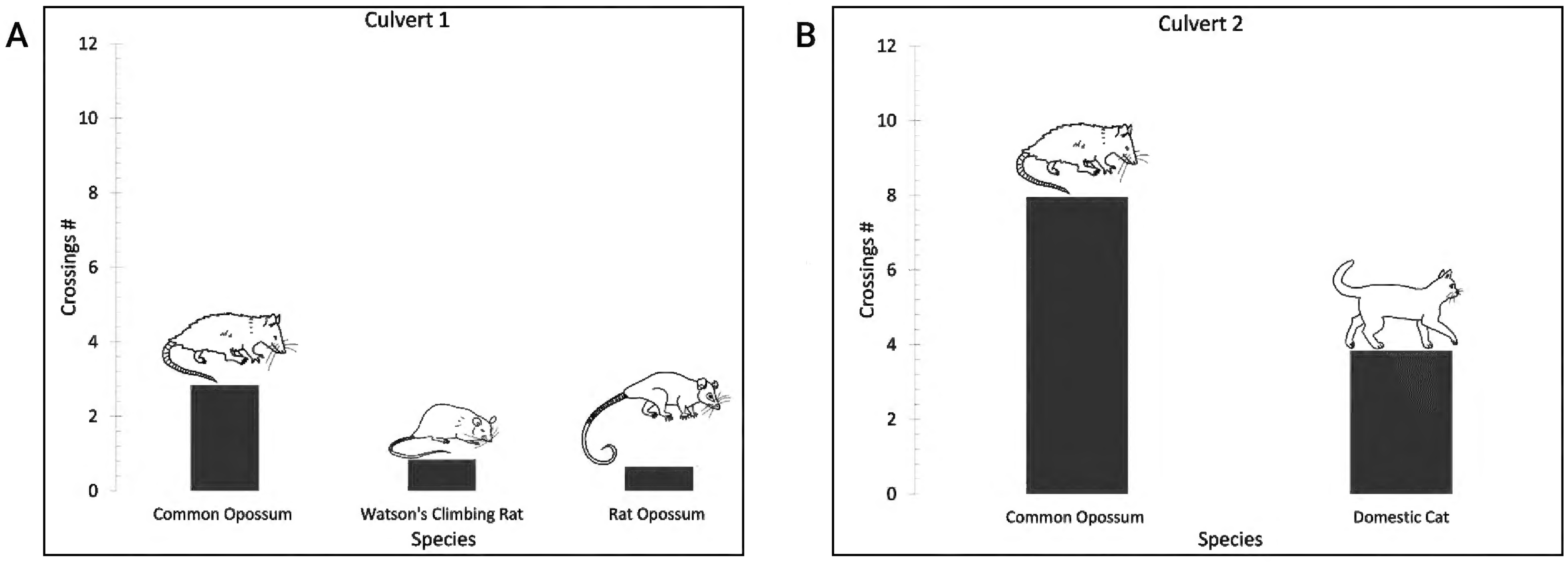

Figure 4. Number of detected crossings by species through Culvert 1 and 2.

Table 1. Presence of species by detected location. "X" indicates that a species was photographed using the underpass or in the land fragment. "E" indicates that a species was observed using the underpass and is expected to be in the land fragment.

Species:	Culvert 1	Culvert 2	Tunnel 1	Tunnel 2	Fragment
Agouti (*Dasyprocta punctata*)			X		X
Black Iguana (*Ctenosaura similis*)					X
Chicken (*Gallus domesticus*)					X
Coati (*Nasua narica*)			X		X
Common Opossum (*Didelphis marsupialis*)	X	X	X	X	X
Cow (*Bos taurus*)					X
Coyote (*Canis latrans*)					X
Domestic Cat (*Felis catus*)		X	X	X	E
Domestic Dog (*Canis familiaris*)			X		X
Gray Fox (*Urocyon cinereoargenteus*)					X
Nine-Banded Armadillo (*Dasypus novemcinctus*)			X	X	X
Northern Tamandua (*Tamandua mexicana*)			X		X
Norway Rat (*Rattus norvegicus*)			X	X	X
Ocelot (*Leopardus pardalis*)			X		E
Olive Sparrow (*Arremonops rufivirgatus*)					X
Rat Opossum (*Micoureus alstoni*)	X				E
Rice Rat (*Oryzomys*)					X
Spiny Pocket Mouse (*Heteromyidae*)					X
Squirrel (*Sciurus variegatoides*)			X		X
Swainson's Thrush (*Catharus ustulatus*)					X
Watson's Climbing Rat (*Tylomus watsoni*)	X				E

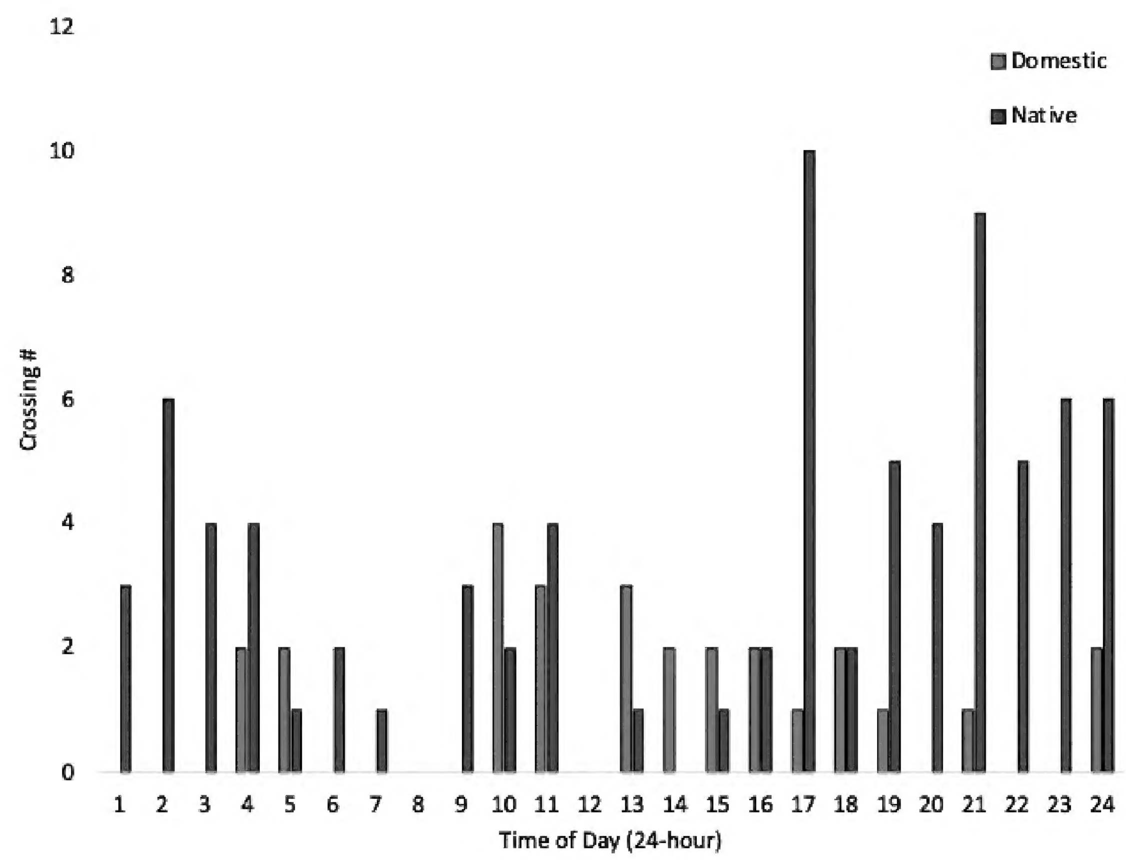

Figure 5. Animal Activity Across the 24-Hour Day. Compares the combined number of crossings by native and domesticated species of mammals across the day. Green represents crossings by native mammals and orange represents crossings by domestic dogs and cats.

Discussion

A total of twelve species used the underpasses to cross Route 606 a combined 108 times over three weeks of observation (Fig. 2). The use of culverts by smaller-sized mammals aligns with one study in Alberta, Canada, that found underpasses such as culverts increase road permeability (Clevenger et al. 2001). The use of the tunnels by small, medium, and large mammals aligns with similar studies in North, South, and Central America (McDonald and St Clair 2004; Clevenger and Waltho 2005). Among the species that used the underpasses in this study, the common opossum, northern tamandua, and nine-banded armadillo are three of the most heavily road-killed species in Costa Rica and were all also found successfully using the tunnels (Fig. 3) (Venegas 2018; Villalobos-Hoffman et al. 2022). Notably, the ocelot, northern tamandua, and rat opossum are all uncommon in the region and of conservation concern (Timm and LaVal 2018). Their use of the underpasses to safely cross Route 606 likely improves their population dynamics by increasing connectivity. Future studies would greatly inform mitigation efforts by quantifying the population-level impacts of areas fragmented by roadways and how these impacts change with underpass usage (Moore et. al. 2023). As most of the native species to use the corridors are nocturnal, it follows that they are most frequented during the night compared to domesticated species (Fig. 5). These four underpasses are effective in the sense that animals used them to cross under Route 606 rather than across the road itself. Though all of the underpasses were successfully utilized, some were frequented more often and by different species than others. The short period for data collection severely limits the ability to accurately quantify the number of species that use these underpasses. As such, it is highly recommended that follow-up studies be conducted over longer periods to assess mitigation and inform future installations. In addition, prior observations of roadkill and species sightings are not available for direct before and after comparison with this dataset to determine quantitative improvements (Camacho and Chinchilla 2013).

Although less than 400 meters apart, Tunnel 1 had noticeably more activity and diversity of species compared to Tunnel 2 (Fig. 3). This difference could be due to the vegetation in the fragments directly surrounding the tunnels. Tunnel 1 has considerably more tree cover surrounding the entrances of the corridor compared to Tunnel 2 (Suppl. material 1: appendix A Image 1 and 2). Culvert 2 also had more vegetation and was used more frequently compared to Culvert 1. As a general principle, wildlife crossing structures will only be as effective as the land and resources surrounding them (Clevenger and Waltho 2005). Although this study was not designed for comparative analysis, one way to increase the efficacy of wildlife underpasses could be to increase the proximity of vegetation in the surrounding land.

Structural shape is another possibility to account for the difference in diversity and abundance between the two tunnels. For instance, in this study, northern tamandua only crossed using the circular Tunnel 1 (Suppl. material 1: appendix A Image 3), despite being photographed less than 5 meters from the entrance of the square Tunnel 2 (Table 1 and Suppl. material 1: appendix A Image 4). This species might prefer the more circular structure and felt more comfortable crossing through it, however, others of the same species in Costa Rica have been recorded using square underpasses to cross roadways (Venegas 2018 and Villalobos-Hoffman et al. 2022). In addition to unequal species usage between underpasses, some vertebrates observed in the fragments surrounding the underpasses were not observed using them during the period of the study. Generally, no single underpass will allow all species to cross a road, because each species has a preference for crossing structure shape and design (Clevenger et al. 2001; McDonald and St Clair 2004; Clevenger and Waltho 2005; Mata et al. 2005). This study's length and methods do not provide enough data to explain why northern tamandua and other species such as coyote and gray fox did not use any of the underpasses even though similar species have used them in other regions (Venegas 2018 and Villalobos-Hoffman et al. 2022; Clevenger et al. 2001).

The presence of barbed wire fences across both entrances of the tunnels is likely also a significant factor influencing which species can use the crossing structures (Suppl. material 1: appendix A Image 5 and 6). Larger species seen crossing or as roadkill across Route 606 prior to underpass construction such as peccary (*Pecari tajacu*) and white-tailed deer (*Odocoileus virginianus*) were not observed in this study and would have had difficulty passing through the fences (Camacho and Chinchilla 2013). The fences at Tunnel 2 have fewer barbed lines and are more degraded than those at Tunnel 1 which may have been another reason Tunnel 2 saw less activity. Because the landowners had originally established these fences for cattle and not to deter wildlife, alternative methods for livestock diversion that allow for other larger species to access the tunnels should be explored and recommended alongside underpass installment.

Conversely, roadside wildlife fencing leading up to underpasses oftentimes increases the effectiveness of crossing structures for large mammals (Huijser et al. 2016). Although Route 606 has minimal barriers, mainly via barbed wire fences scattered across pasture boundaries, there had been no concurrent construction of fencing during underpass construction to direct wildlife. Fences can be expensive to install and maintain and have the potential to directly or indirectly harm animals that encounter them (Jones 2014). However, previous

studies have found that underpasses with more than 5 km of fences surrounding them are considerably more effective at reducing wildlife collisions and improving underpass usage than structures with little or no fencing (Huijser et al. 2016).

The domestic animals that traveled across the underpasses likely traveled from the farms and houses directly surrounding them. Despite the fact that both domestic dogs and cats severely hunt wildlife globally, there is little evidence as to whether their presence could deter local species from using underpasses (Mysłajek et al. 2020). However, their use of these structures does facilitate access across landscapes to areas that they could potentially harm. Many of the sightings in this study were repeated crossings from individual animals. For instance, a pair of dogs constituted the 15 crossings across tunnel 1 and the cat found using Culvert 2 was the same individual for all four crossings (Figs 2A, 3B). Informing the residents that surround these underpasses of the potential impacts their animals can cause may alleviate some of these disturbances.

Vertebrates are not the only organisms using the underpasses. Primarily two species of insects, army ants (*Eciton burchellii*) and termites (*Atta cephalotes*) were recorded using the underpasses to cross under Route 606 in foraging trails. These observations occurred during in-person visitations to the underpasses; however, they were not included in the results because this study was not designed to quantify use by insects. Insect roadkill and decreasing insect abundance are threats to the health of global ecosystems, and a study surveying the use of these underpasses to conserve insect populations would be beneficial for conservation efforts (New 2015).

Because road infrastructure inevitably grows with the human population, it is vital for transportation agencies and urban planners to consider the ways this growth could harm local ecosystems. Continued investment in wildlife crossing structures will likely help conserve species threatened by the fragmentation and habitat loss caused by roadways. Future studies would benefit from surveying a greater number of underpasses with a variety of different attributes over longer periods. This research is necessary to assess what features would make animal crossing structures more effective for a greater variety of species. The data from this study support the claim that the underpasses built under Route 606 have helped reduce the impacts of fragmentation by allowing mammal species to travel between fragments. Further studies will help inform the optimal design of future crossing structures.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Funding

No funding was reported.

Author contributions

Conceptualization: ERT. Data curation: ERT. Formal analysis: ERT. Investigation: ERT. Methodology: ERT. Project administration: ERT. Visualization: ERT. Writing - original draft: ERT. Writing - review and editing: ERT.

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Data availability

The data that support the findings of this study are available in the main text or Supplementary Information, and all additional data, that is not directly included, can be provided upon request by the author.

References

Abra FD, da Costa CA, Garbino GST, Medici EP (2020) Use of unfenced highway underpasses by lowland tapirs and other medium and large mammals in central-western Brazil. Perspectives in Ecology and Conservation 18(4): 247–256. https://doi.org/10.1016/j.pecon.2020.10.006

Barbosa P, Schumaker NH, Brandon KR, Bager A, Grilo C (2020) Simulating the consequences of roads for wildlife population dynamics. Landscape and Urban Planning 193: 103672. https://doi.org/10.1016/j.landurbplan.2019.103672

Beier P, Majka D, Newell S, Garding E (2008) Best management practices for wildlife corridors. Northern Arizona University 1(3): 1–14.

Camacho CF, Chinchilla R (2013) Technical report for the location of wildlife crossings in the Naitional Highway 606 Guacimal–Monteverde, Puntarenas. UGA Costa Rica.

Clevenger AP, Waltho N (2005) Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121(3): 453–464. https://doi.org/10.1016/j.biocon.2004.04.025

Clevenger AP, Chruszcz B, Gunson K (2001) Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38(6): 1340–1349. https://doi.org/10.1046/j.0021-8901.2001.00678.x

Didham RK (2010) Ecological consequences of habitat fragmentation. Encyclopedia of life sciences 61: 1–11. https://doi.org/10.1002/9780470015902.a0021904

Dixo M, Metzger JP, Morgante JS, Zamudio KR (2009) Habitat fragmentation reduces genetic diversity and connectivity among toad populations in the Brazilian

Atlantic Coastal Forest. Biological Conservation 142(8): 1560–1569. https://doi.org/10.1016/j.biocon.2008.11.016

Haddad NM, Brudvig LA, Clobert J, Davies KF, Gonzalez A, Holt RD, Townshend JR (2015) Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances 1(2): e1500052. https://doi.org/10.1126/sciadv.1500052

Huijser MP, Fairbank ER, Camel-Means W, Graham J, Watson V, Basting P, Becker D (2016) Effectiveness of short sections of wildlife fencing and crossing structures along highways in reducing wildlife–vehicle collisions and providing safe crossing opportunities for large mammals. Biological Conservation 197: 61–68. https://doi.org/10.1016/j.biocon.2016.02.002

Jones PF (2014) Scarred for life: The other side of the fence debate. Human-Wildlife Interactions 8(1): 150–154. https://www.jstor.org/stable/24874896

Mata C, Hervas I, Herranz J, Suarez F, Malo JE (2005) Complementary use by vertebrates of crossing structures along a fenced Spanish motorway. Biological Conservation 124(3): 397–405. https://doi.org/10.1016/j.biocon.2005.01.044

McDonald W, St Clair CC (2004) Elements that promote highway crossing structure use by small mammals in Banff National Park. Journal of Applied Ecology 41(1): 82–93. https://doi.org/10.1111/j.1365-2664.2004.00877.x

Moore LJ, Petrovan SO, Bates AJ, Hicks HL, Baker PJ, Perkins SE, Yarnell RW (2023) Demographic effects of road mortality on mammalian populations: A systematic review. Biological Reviews of the Cambridge Philosophical Society 98(4): 1033–1050. https://doi.org/10.1111/brv.12942

Mullu D (2016) A review on the effect of habitat fragmentation on ecosystem. Journal of Natural Sciences Research 6(15): 1–15.

Mysłajek RW, Olkowska E, Wronka-Tomulewicz M, Nowak S (2020) Mammal use of wildlife crossing structures along a new motorway in an area recently recolonized by wolves. European Journal of Wildlife Research 66(5): 79. https://doi.org/10.1007/s10344-020-01412-y

Naranjo-Ureña R, Ruiz-Cubillo P, Ulate-Castillo A, Valverde-Cordero C, Barrantes-Jiménez R, Elizondo-Salas AL (2019) Informe de Evaluación RUTA NACIONAL No. 606 Sección Guacimal–Santa Elena. https://www.lanamme.ucr.ac.cr/repositorio/handle/50625112500/2138

New TR (2015) Landscape connectivity for urban insects. Insect conservation and urban environments, 203–212. https://doi.org/10.1007/978-3-319-21224-1_10

Timm RM, LaVal RK (2018) Mammals [of Monteverde]: 2000–2018. Monteverde: ecology and conservation of a tropical cloud forest, 3–16. Bowdoin Scholars' Bookshelf. https://doi.org/10.1093/oso/9780195095609.003.0013

Venegas M (2018) Functionality of underground structures as wildlife passages in the Hacienda Barú, Puntarenas, Costa Rica. National Bachelor of Science Project, National University of Costa Rica, Heredia, Costa Rica.

Villalobos-Hoffman R, Ewing JE, Mooring MS (2022) Do wildlife crossings mitigate the roadkill mortality of tropical mammals? A case study from Costa Rica. Diversity 14(8): 665. https://doi.org/10.3390/d14080665

Wilson MC, Chen XY, Corlett RT, Didham RK, Ding P, Holt RD, Yu M (2016) Habitat fragmentation and biodiversity conservation: Key findings and future challenges. Landscape Ecology 31(2): 219–227. https://doi.org/10.1007/s10980-015-0312-3

Supplementary material 1

Underpass Site Images, Quantitative Underpass Crossings by Species, Examples of Camera Trap and Corresponding Mud Track Data

Author: Eleanor R. Terner

Data type: tablec and images (PDF file)

Explanation note: The following images illistrate the ground-level and aerial view of the underpasses. In addition, there are examples of camera trap images paired with the track station print of the same species.

Link: https://doi.org/10.3897/neotropical.18.e102809.suppl1